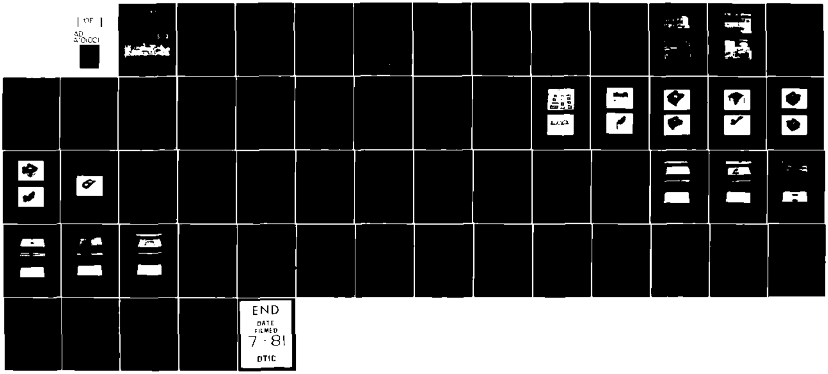
AD-A101 021 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 11/2
INVESTIGATION OF DETERIORATION OF BRICK IN NAVIGATION LOCK CONT--ETC(U)
SEP 80 R H DENSON, G S WONG, T B HUSBANDS
UNCLASSIFIED WES/MP/SL-80-14 NL



MISCELLANEOUS PAPER SL-80-14

INVESTIGATION OF DETERIORATION OF BRICK IN NAVIGATION LOCK CONTROL HOUSE STRUCTURES, TULSA DISTRICT

by

Robert H. Denson, G. Sam Wong, and Tony Husbands

Structures Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1980

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Army Engineer District, Tulsa
Tulsa, Okla. 74102

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: Miscellaneous Paper SL-80-14	2. GOVT ACCESSION NO. AD-A101 027	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): INVESTIGATION OF DETERIORATION OF BRICK IN NAVIGATION LOCK CONTROL HOUSE STRUCTURES, TULSA DISTRICT		5. TYPE OF REPORT & PERIOD COVERED: Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): R. H. Denson, G. S. Wong, T. B. Husbands		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U. S. Army Engineer Waterways Experiment Station, Structures Laboratory, P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Engineer District, Tulsa, P. O. Box 61, Tulsa, Okla. 74102		12. REPORT DATE: September 1980
		13. NUMBER OF PAGES: 53
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): WES/MP/SL-80-14		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, Springfield, Va. 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Bricks
Control structures
Locks (Waterways)
Navigation dams
Protective coatings
Structural models

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The deterioration of brick in certain control house structures at five navigation locks was characterized by partial or complete separation of laminations from the face of several bricks. Some of the laminations had fallen completely off. Deteriorated and nondeteriorated samples were removed from several structures and were evaluated by physical testing and petrographic examination. The deterioration mechanism was identified as moisture intrusion accompanied by freezing and thawing. Six model walls were constructed (continued)

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (continued).

and each was coated with a different protective coating to determine the effectiveness of such treatment. The six coatings were rated in order of efficiency in producing protection with urethane coatings outperforming epoxy and silicone coatings.

PREFACE

This study was authorized by DA Forms 2544 numbers TPD 78-06 (27 April 1978) and TJA 79-4 (3 Nov 1978), U. S. Army Engineer District, Tulsa. It was conducted by the Structures Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Army Engineer District, Tulsa. The work was accomplished under the general supervision of Messrs. Bryant Mather, Chief, Structures Laboratory; J. M. Scanlon, Chief, Concrete Technology Division; and G. C. Hoff, Chief, Materials and Concrete Analysis Group. Other staff members actively participating in the investigation were Messrs. Robert H. Denson, G. Sam Wong and Tony B. Husbands. Mr. Denson prepared the report of the physical testing, Mr. Wong prepared the report of the petrographic examination and Mr. Husbands prepared the report of the work on coatings. The project was coordinated with Mr. John Nixon, District Architect, Tulsa District.

Commanders and Directors of WES during the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. Fred R. Brown.

CONTENTS

	Page
PREFACE	1
CONVERSION FACTORS, INCH-POUND UNITS TO METRIC (SI) UNITS OF MEASUREMENT	3
PART I: BACKGROUND	5
PART II: SAMPLES AND PHYSICAL TESTING	6
PART III: PETROGRAPHIC EXAMINATION	24
PART IV: PROTECTIVE COATINGS	28
PART V: FAILURE MECHANISM AND RECOMMENDATIONS	39
REFERENCES	41
APPENDIX A: ARCHITECT'S SKETCHES	

CONVERSION FACTORS, INCH-POUND UNITS TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
mils	0.0254	millimetres
inches	2.54	centimetres
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	0.006894757	megapascals
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

INVESTIGATION OF DETERIORATION OF BRICK IN NAVIGATION LOCK CONTROL HOUSE STRUCTURES, TULSA DISTRICT

PART I: BACKGROUND

1. In May 1978, Mr. Robert H. Denson, Structures Laboratory (SL), WES, met with Mr. John Nixon, District Architect, Tulsa District, to discuss the problem of deterioration of brick. Mr. Nixon stated that the problem was evident in several structures at each of five navigation locks. The deterioration was characterized by a layer approximately 1/8 in. in thickness of the face of the brick spalling off followed by continued deterioration. This ranged in intensity from an intact small separation to complete loss of the face of the brick.

2. Visits were made to the five navigation locks to observe and photograph the affected structures. At each site certain deteriorated and nondeteriorated bricks were selected to be used in the investigation. Sketches of the locations of these bricks within each structure were made and are included in this report as Appendix A.

3. The bricks marked for testing were removed from the structures by Tulsa District personnel and shipped to WES.

4. The following is a list of the navigation structures, and their locations, that were involved in the investigation.

Name	Location (near)
a. W. D. Mayo L&D #14	Ft. Smith, Ark
b. Robert S. Kerr L&D #15	Sallisaw, OK
c. Webbers Falls L&D #16	Webbers Falls, OK
d. Chouteau L&D #17	Chouteau, OK
e. Newt Graham L&D #18	Inola, OK

PART II: SAMPLES AND PHYSICAL TESTING

Description of Test Bricks

5. Bricks were chosen in pairs where feasible, either near or adjacent to each other, with one being deteriorated and the other non-deteriorated. In addition six new, unused bricks were supplied by the Tulsa District from supplies being used on current work for inclusion in the investigation. Table 1 lists the as-received conditions of the bricks. The nominal size of the bricks was 7-11/16 in. by 3-11/16 in. by 2-5/16 in.

Description of Tests

6.

a. General. After the bricks were received in the laboratory they were photographed and cleaned of mortar. Bricks from each lock were chosen in a manner that allowed as many tests as possible to be performed on each group. Table 2 lists the specimens from each lock and the tests performed.

b. Tests performed. Information received from the Tulsa District stated that the job specifications for Locks and Dams 14, 15, 16 and 18, required the bricks for exterior facing to conform to American Society for Testing and Materials (ASTM) Standard C 216-64,[1] Type FBS either grade SW or MW. This standard, in addition to stating the specifications for the bricks, states that the bricks shall be sampled and tested in accordance with ASTM Methods C 67. The compressive strength, absorption, and freezing and thawing tests were performed on the bricks, or part of brocks, according to the provisions of ASTM: C 67.

Photo 1. Typical Control House Structure (L&D 14)

Photo 2. Typical Conditions-nondeteriorated; face popoff; intact face popoff. Control house structure (L&D 15)

Photo 3. Typical conditions-inside face of parapet wall-control house structure (L&D 15)

Photo 4. Typical conditions-visitor center (L&D 15)

TABLE 1

As-Received Description of Bricks

Brick No.	L & D No.	As-Received General Description
1A[a]	14	Partially broken in removal: some visible layering (separation)
1B[a]	14	Almost destroyed[b] in removal
2A	14	Some face damage in removal
2B	14	Damaged and broken in removal
3A	14	Broken in half lengthwise in removal
3B	14	Broken in half lengthwise in removal
4A	15	No face damage but broken in half lengthwise in removal
4B	15	Slightly damaged in removal--layering effect obvious 1/4 distance into face
5A	15	Only slight damage in removal
5B	15	Completely destroyed in removal
6A	15	No damage
6B	15	No damage
7A	15	Slight damage in removal
7B	15	Slight damage in removal
8A	16	Completely destroyed in removal
8B	16	Half a brick: destroyed in removal
9A	17	Only slight damage to back of brick
9B	17	Completely destroyed
10A	17	Mostly destroyed in removal
10B	17	Mostly destroyed in removal
11A	17	Mostly destroyed in removal
11B	17	Mostly destroyed in removal
12A	18	Slight damage caused by layering effect
12B	18	Mostly destroyed in removal
13A	18	No damage
13B	18	Destroyed in removal

TABLE 1 (Continued)

As-Received Description of Bricks

Brick No.	L & D No.	As-Received General Description
14A	18	Destroyed in removal
14B	18	Some face remaining - other destroyed
15A	18	Destroyed in removal
15B	18	Destroyed in removal
IN-6N	New	Unused

NOTES:
(a) A - designation refers to nondeteriorated brick
B - designation refers to deteriorated brick
(b) The description "destroyed" refers to the brick being broken into smaller pieces but the pieces are usable for certain tests.

TABLE 2

Summary of Specimens and Tests

Specimen No.		Petrographic Examination (PE)[b]
	Lock No. 14	
1A, 1B		Petrographic examination (PE)[b]
$2A_1$[a]		Compressive strength (CS)
$2A_2$		Freezing-Thawing (F-T)
$2B_1$		CS
$2B_2$		Absorption (ABS)
$3A_1$		CS
$3A_2$		F-T
$3B_1$		ABS
$3B_2$		F-T
	Lock No. 15	
4A, 4B		PE
$5A_1$		F-T
$5A_2$		CS
5B		ABS
$6A_1$		F-T
$6A_2$		CS
$6B_1$		CS
$6B_2$		ABS
7A, 7B		PE
	Lock No. 16	
8A, 8B		PE

TABLE 2 (Continued)

Summary of Specimens and Tests

Specimen No.	Petrographic Examination (PE)[b]
Lock No. 17	
$9A_1$	CS
$9A_2$	F-T
$10A_1$	CS
$10A_2$	ABS
10B	F-T
11A, 11B	PE
Lock No. 18	
$12A_1$	F-T
$12A_2$	CS
$12B_1$	CS
$12B_2$	ABS
$13A_1$	F-T
$13A_2$	CS
$13B_1$	ABS
$13B_2$	F-T
$14A_1$	ABS
$14A_2$	F-T
$14B_1$	CS
$14B_2$	ABS
15A, 15B	PE

TABLE 2 (Concluded)

Summary of Specimens and Tests

Specimen No.	Petrographic Examination (PE)[b]
New Unused Bricks	
1N	CS
2N	F-T
3N	ABS
4N	PE

NOTE:
(a) Subscript number indicates specimens taken from same brick.
(b) See Petrographic Examination report for all bricks marked PE.

Test Results

7. Test results are discussed below.

   a. Compressive strength. The specimens chosen for this test were capped with plaster and loaded to failure in a testing machine. The compressive strength of each was then calculated by dividing the total load by the average of the gross areas of the upper and lower bearing surfaces of the specimen. Table 3 lists the compressive strengths of the specimens so tested. All specimens met the requirements for strength. The new brick ($1N_1$ and $1N_2$) was of a different class.

   b. Absorption. The absorption specimens were first dried for at least 24 hr. at 230°F (110°C) and then weighed after they had cooled. They were then immersed in clean water at a temperature of approximately 73°F for 24 hr, surface-dried and weighed. The specimens were then returned to the immersion vessel and subjected to a 5-hr boiling test. The water at 73°F was brought to a boil within 1 hr and then boiled continuously for 5 hours. The specimens were then allowed to cool to approximately 73°F, removed from the vessel, surface-dried and weighed. Table 4 lists the results of this test procedure.

   c. Freezing and thawing test (F-T). The specimens were prepared for testing by first drying them at a temperature of 230°F for at least 24 hr and then weighing them after they had cooled. They were then immersed in water for 4 hr prior to the beginning of the F-T test. The specimens were then placed face down in a pan and covered with water to a depth of 1/2 inch over the top of the brick. The pan and specimens were then placed in the freezing chamber for 20 hours. At the end of the freezing period, the pan and specimens were totally immersed in a water-filled

TABLE 3

Compressive Strength

Specimen No.	Compressive Strength, psi
$2A_1$	7,055
$2B_1$	5,860
$3A_1$	7,410
$5A_2$	7,880
$6A_2$	9,490
$6B_1$	8,400
$9A_1$	5,405
$10A_1$	6,520
$12A_2$	8,460
$12B_1$	6,470
$13A_2$	8,340
$14B_1$	4,820
$1N_1$	26,560
$1N_2$	28,180

NOTE: Minimum required strengths (ASTM C 216).

Individual brick:	Grade SW	2500 psi
	Grade MW	2200 psi
Average of five brick:	Grade SW	3000 psi
	Grade MW	2500 psi

TABLE 4

Absorption Test Results

Specimen No.	24-hr Immersion Percent Absorption	5-hr Boiling[a] Percent Absorption	Saturation[b] Coefficient
2B2	9.8	11.2	0.875
$3B_1$	10.1	11.2	0.902
5B	11.5	13.1	0.878
$6B_2$	9.1	10.6	0.858
9B	10.7	11.9	0.899
$10A_2$	10.0	11.6	0.862
$12B_2$	10.2	11.2	0.911
$13B_1$	10.0	11.0	0.909
$14A_1$	10.2	11.4	0.895
$14B_2$	9.6	10.6	0.906
3N	4.0	4.0	1.000

(a) Maximum Values: Grade SW 20.0 Percent
Individual brick Grade MW 25.0 Percent

(b) Maximum values: Grade SW 0.80
Individual brick Grade MW 0.90

thawing tank for 4 hr. The next cycle was begun by removing the pan and specimens from the thawing tank, draining all but 1/2-inch depth from the pan and placing it back in the freezing chamber. The specimens were thus subjected to 50 cycles of F-T. While the specimens were being cycled, observations were made of any change in their conditions. At the end of 50 cycles the specimens were dried and weighed.

8. Table 5 lists the F-T results, with the loss of weight being a percentage of the original dry weight of the specimens. Condition changes are given in the remarks column.

Discussion of Physical Tests

9. The compressive strengths ranged from 4820 psi to 9490 psi with an average value of 7175 psi. By comparing deteriorated and nondeteriorated pairs of bricks it was seen that the deteriorated brick had a strength level that was approximately 1100 psi less than the nondeteriorated brick. However, the deteriorated brick has a strength level greater than the requirement by a factor of 2.5 to 3.0.

10. The maximum allowable value of absorption (5-hr boiling) was 20 percent for Grade SW and 25 percent for Grade MW. The test specimens had adsorption values of 10 to 13 percent, well below the requirement. Eleven of the saturation coefficients were close to the maximum allowable value of 0.90 (MW). Those values that exceeded the Grade MW allowable limit did so by very small amounts. In addition there seemed to be no significant pattern or difference between deteriorated and nondeteriorated bricks.

11. ASTM C 216 does not require that bricks be tested for resistance to F-T unless they fail to conform to the requirements for absorption and saturation coefficient or for compressive strength and absorption. However, the F-T tests were made. Had they been required, the requirements for compliance, as given in C 216 are "Grade SW...no breakage and not greater than 0.5 per cent loss in dry weight of any individual

TABLE 5

Results[a] of Freezing and Thawing Test

Specimen No.	Weight Loss Percent	Remarks
$2A_2$	0.56	Very slight change at end of test
$3A_2$	0.49	Face-layering in "new" and "old" face at Cycle No. 19
$3B_2$	2.8	Face-layering began at Cycle No. 18
$5A_1$	0.50	Face-layering began at Cycle No. 18
$6A_1$	0.25	Very slight change at end of test
$9A_2$	5.70	Face cracked at Cycle No. 14 Face-layering very pronounced at Cycle No. 18
10B	2.2	Face crack at Cycle No. 19
$12A_1$	0.12	Face-layering at Cycle No. 23
$13A_1$	0.24	Face-layering at end of test
$13B_2$[b]	0.62	Only slight change end of test
$14A_2$	0.68	Middle cracked at Cycle No. 10 Face-Layering at Cycle No. 23
2N	0.05	No change

(a) See Photos 5-17 for "before" and "after" conditions of each specimen tested.

(b) Specimen $13B_2$: Back face of brick was used as test face due to destruction of front face in removal.

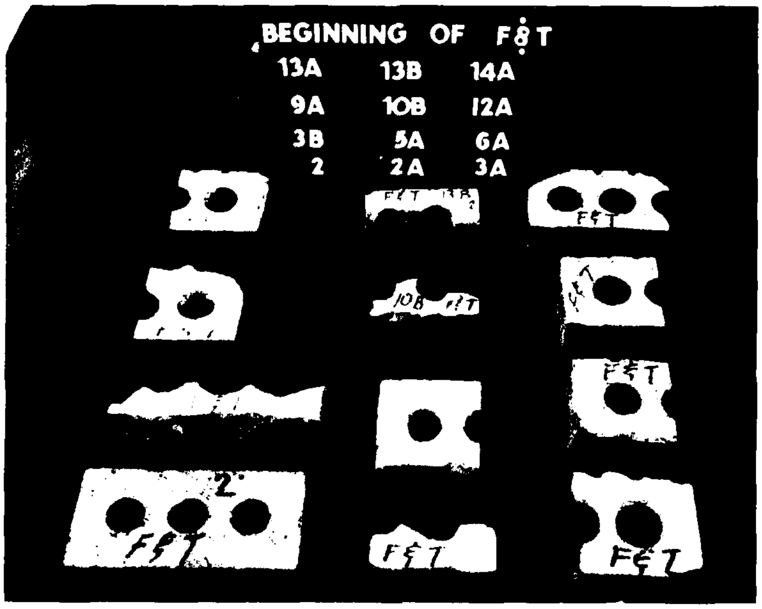


Photo 5. Freeze-thaw samples at 0 cycles

Photo 6. Sample 2N - 50 cycles F-T

Photo 7. Sample $2A_2$ - 50 cycles F-T

Photo 8. Sample $3B_2$ - 50 cycles F-T

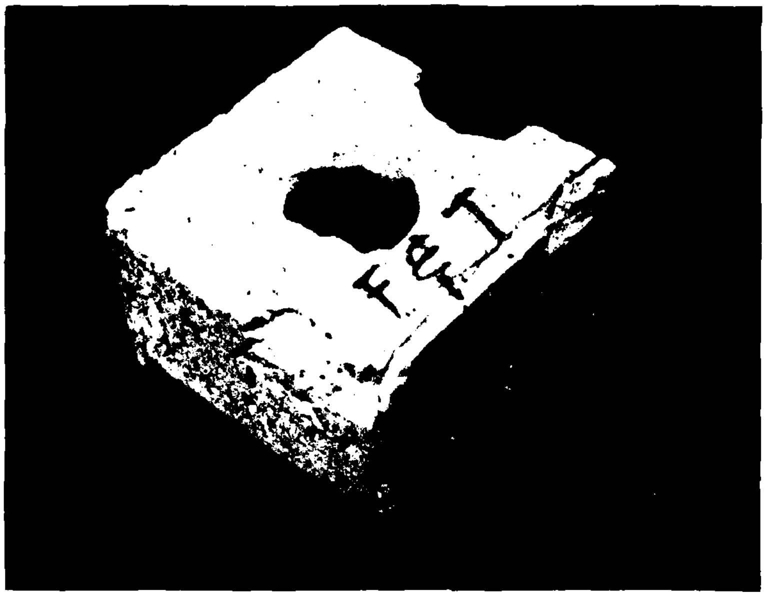


Photo 9. Sample $5A_1$ - 50 cycles F-T

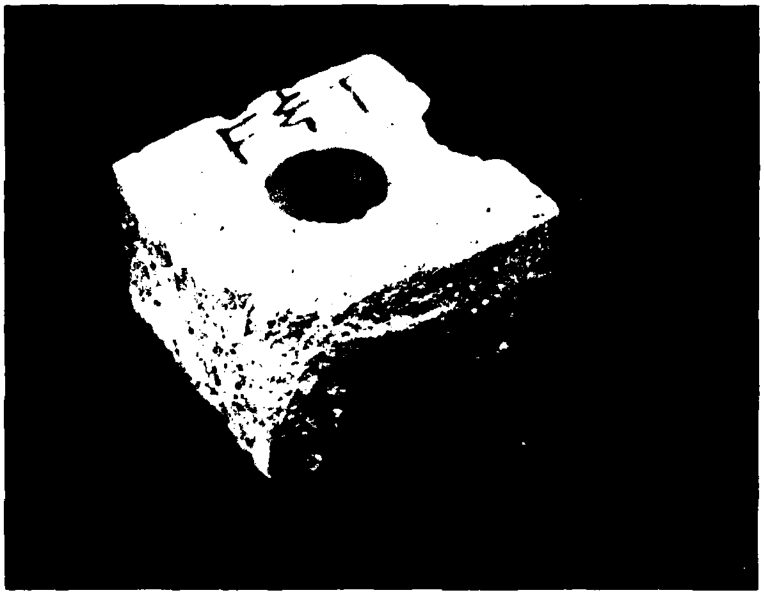


Photo 10. Sample $6A_1$ - 50 cycles F-T

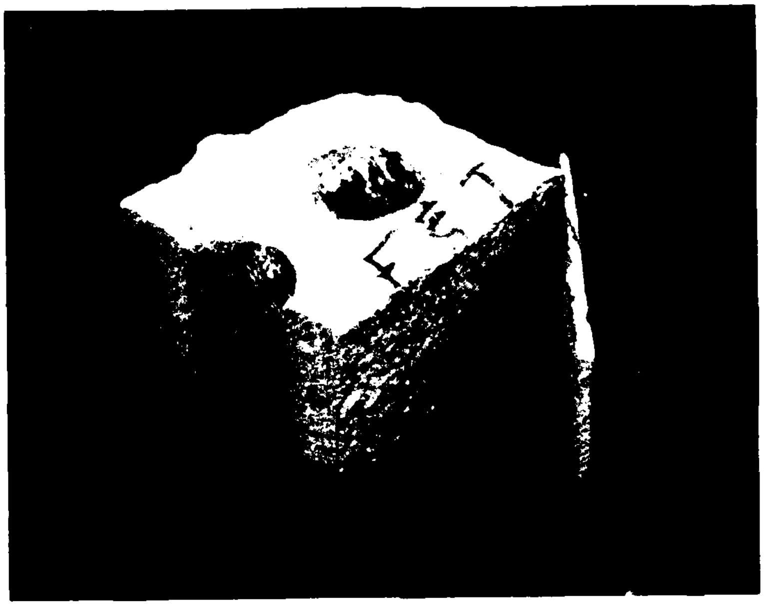


Photo 11. Sample $9A_2$ - 50 cycles F-T

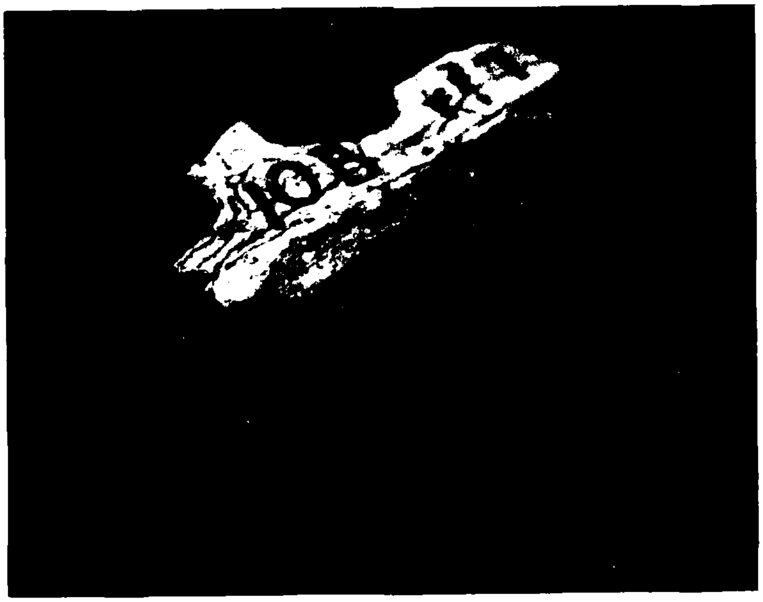


Photo 12. Sample 10_B - 50 cycles F-T

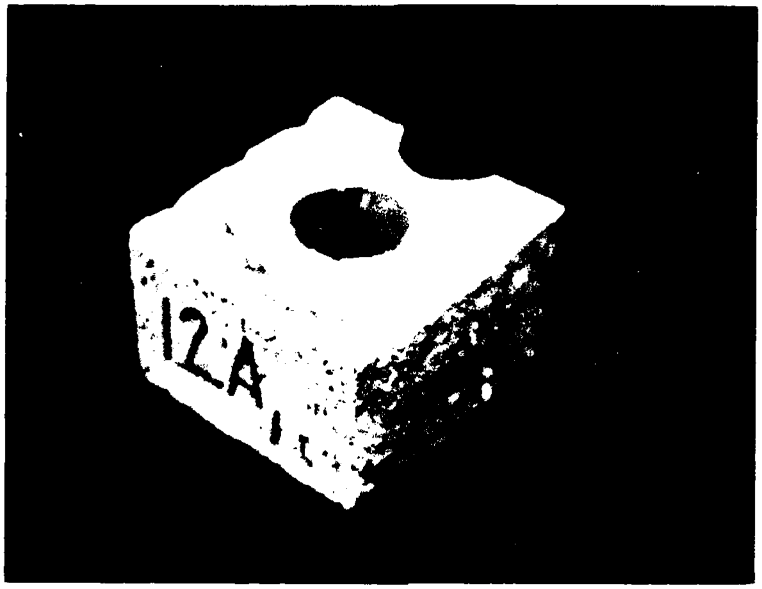


Photo 13. Sample $12A_1$ - 50 cycles F-T

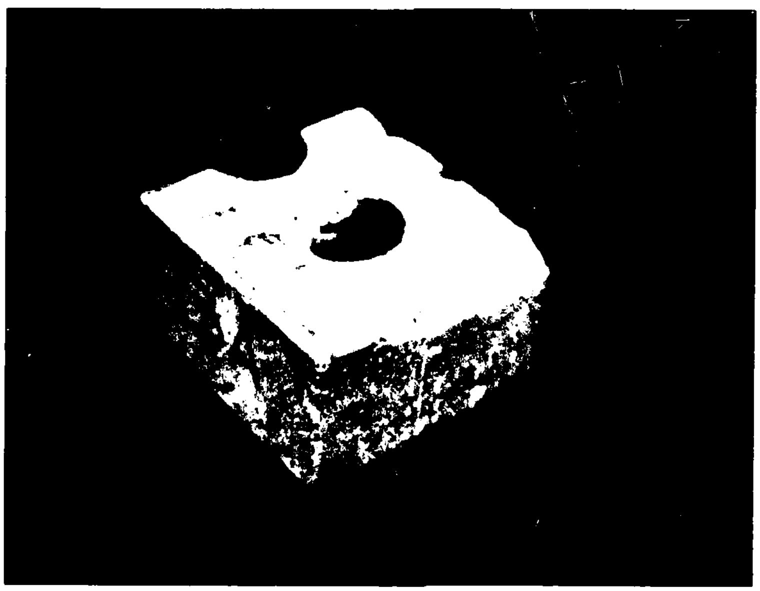


Photo 14. Sample $13A_1$ - 50 cycles F-T

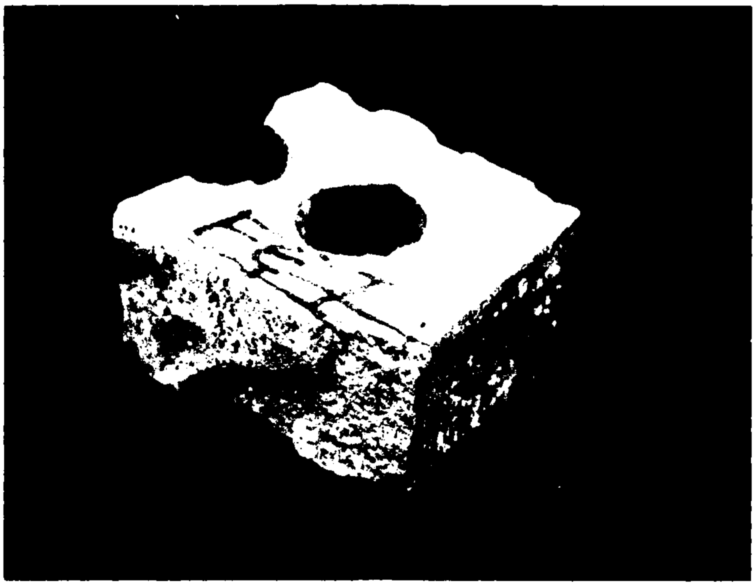


Photo 15. Sample $13A_2$ - 50 cycles F-T

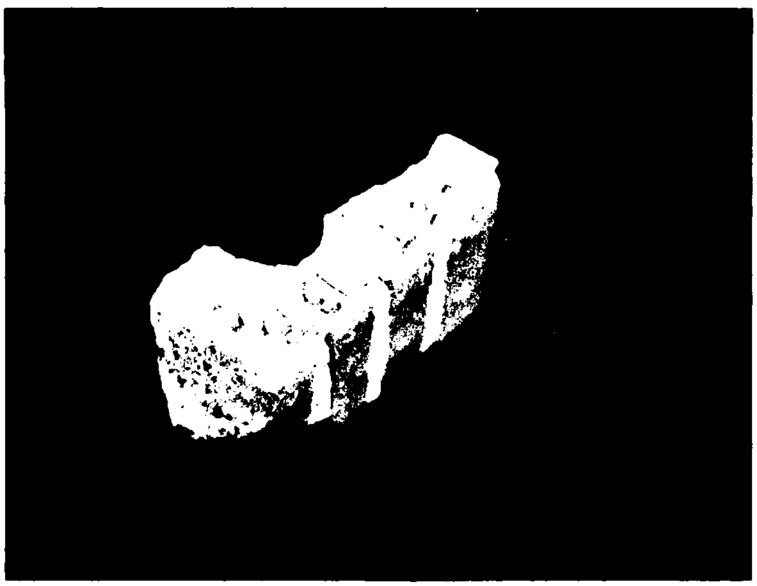


Photo 16. Sample $13B_2$ - 50 cycles F-T
(back face of brick tested)

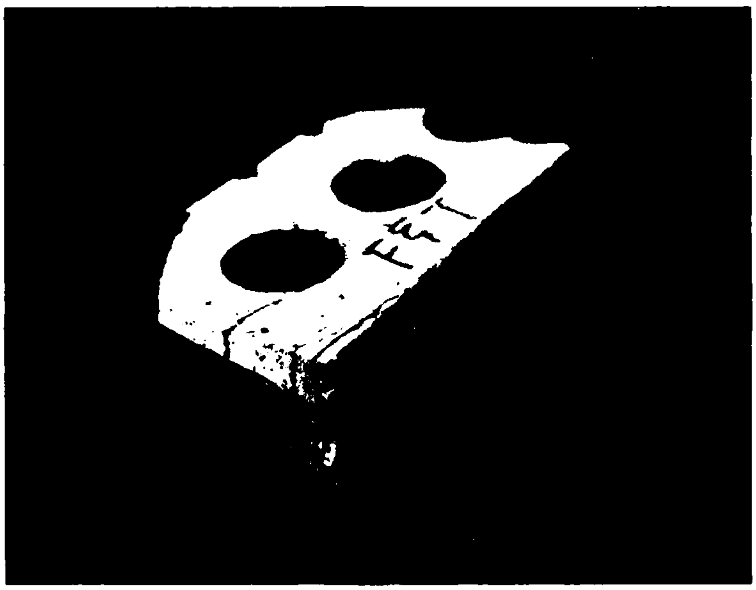


Photo 17. Sample $14A_2$ - 50 cycles F-T

brick." after 50 cycles. Grade SW was not specified, hence the requirement cannot be invoked for acceptance. Therefore the freezing-and-thawing results are of use as an indication of mechanism only. However, had the provisions cited above been applicable, eight of the bricks tested would have been regarded as non-compliant. In addition field observations had indicated that frost action may have been an integral part of the total failure mechanism.

12. The results show that the F-T test duplicated, in varying degrees, the deterioration taking place in the structures. The only specimens not showing face splitting were $2A_2$, 6A, and $13B_2$. The other specimens all showed cracking or layer separation or both. Specimen $9A_2$ suffered a complete separation of a 1/4-in. layer from the face. Several of the others lost portions of the face and nearly all had several layer separations parallel to the face of the specimen. The layers all appear to be approximately 1/8-in. to 5/16-in. thick and will eventually lead to complete disintegration of the brick if some protective mechanism is not implemented.

PART III: PETROGRAPHIC EXAMINATION

13. Pairs of bricks consisting of one that was spalled and one that appeared intact were sampled at each site. The petrographic examination was performed to detect possible differences between the spalled and intact bricks. It was thought that if some bricks had not been completely fired they might be more susceptible to volume changes with moisture changes and this could lead to the observed spalling. If this was the case, it would show an underburned clay or clays in the failed bricks. Since in the six pairs of samples the spalled portion of brick was always missing it seemed desirable also to examine an example of the material that actually broke off; for this reason the spalled part of one brick was included.

Test Procedure

14. All of the bricks were broken during removal from the structures. The broken pieces were fitted together so the spalled surfaces could be recognized and measurements and examinations could be made.

15. All of the bricks were examined with a stereomicroscope, to detect any differences between the intact and the spalled bricks. Brick No. 1A was cut normal to the exposed surface and then examined.

16. A portion of each exposed brick surface was ground to pass a 45-μm (No. 325) sieve and examined by X-ray diffraction. Selected particles from spalled surfaces were ground in water to make slurries and were spread on glass slides. These slurries were air dried and the dried film examined by X-ray diffraction.

17. All X-ray patterns were made with an X-ray diffractometer using nickel-filtered copper radiation.

18. Two small cores, about 1/2 in. in diameter, were taken from the interior portion of brick 4B. The absorption of these two cores and of the spalled piece was determined by CRD-C 107-69.[2]

Results

19. All of the six spalled bricks selected to show deterioration were characterized by rough exterior surfaces where some of the original smooth surface had fallen away. The depth of this spalling ranged from 1/8 to 1/4 in. In addition, several of these bricks showed cracking parallel to the surface. In no case was the depth of cracking more than 1 in. The six intact bricks were selected to obtain undamaged samples for comparison. This examination revealed that brick 1A contained parallel cracking to a depth of 1 in. and brick 11A contained shallow cracks, behind and parallel to their exposed surfaces. However, these exposed surfaces had not yet fallen off the two bricks. This showed that the damage was also present in some bricks from which the surface had not yet spalled.

20. The original size of the used brick was 7-11/16 in. by 3-11/16 in. by 2-5/16 in. while the new brick was slightly smaller at 7-11/16 in. by 3-9/16 in. by 2-3/16 in.

21. Samples 4A and 4B were a lighter grayish orange (6B5)[3] than the other used bricks which were also grayish orange (6B6).[3] The new brick was light brown (7D6).[3]

22. The overall mineralogical composition of all of the bricks was similar. All contained quartz and hematite. Mullite, spinel, and potassium feldspars were also present in some of the bricks. Spinel and potassium feldspars were tentatively identified by a single X-ray diffraction peak. No clay minerals were detected in any of the X-ray patterns. Therefore, there is no indication that any of the bricks were underburned.

23. Close examination of these bricks showed that they contained small reddish-brown, yellowish, and whitish particles in a fine-grained matrix. Hand-picking and subsequent X-ray diffraction examination showed that the reddish brown particles were composed of quartz and hematite; the yellowish particles were composed of quartz, mullite, and hematite; and the whitish particles were composed of quartz and mullite.

24. The examination of the spalled off piece did not show any significant difference between it and the rough surfaces of the spalled bricks which represented the back of a typical spall.

25. There was nothing detectably different between the composition of the new unused brick and the composition of the unspalled and spalled bricks.

26. The absorptions of the three pieces that were tested were:

Brick 4B	Absorption Percent
Interior Core 1	12.7
Interior Core 2	12.4
Average	12.6
Exterior surface spall	4.5

This indicates a significant difference with lower absorption on the exterior portion of the brick.

Discussion

27. No significant mineralogical differences were found. This suggests that composition was not a factor in causing the spalling. The absence of mineralogical differences indicates that the spalling was not caused by inadequately fired clay minerals remaining in the bricks.

28. There was no evidence of popouts caused by porous contamination or expansive chemical reaction.

29. The spalling appears to be the result of freezing and thawing in which portions of some bricks were critically saturated with water. The presence of cracks in some of the bricks that have not yet spalled suggests that the effect is more widespread than was realized during field observations. It is probable that not all bricks were affected

equally because of differences in porosity of individual bricks, the location of the individual bricks in the structure and consequently differences in access to moisture. The difference between the higher absorption of the interior portion of bricks and the lower absorption of the outer surface (Table 1) would seem to agree with the suggestion that frost action is responsible for the spalling. Probably water entered the brick surface of the buildings along cracks at the boundary between brick and mortar; the exterior surface was critically saturated at about one-third of the water required to saturate critically the interior of the brick. Thus hydraulic pressure destroyed the exterior surface and separated it from the more porous interior.

PART IV: PROTECTIVE COATINGS

30. In order to evaluate the effectiveness of candidate protective coatings a review of available materials and methods was made. Five coatings were chosen, as follows:

Material	Panel No.	Chemical Classification
A*	2 and 3	Polyurethane
B	5	Epoxy resin
C	1	Epoxy resin
D	6	Silicone
E	4	Epoxy resin

* A solvent thinner was used with material A.

31. Six test panels were made using bricks taken from landscape planters at L&D No. 18. Twelve bricks (six deteriorated and six non-deteriorated), were used in each panel, with each panel being three bricks long and four courses high. The panels were constructed in the vertical position using mortar very similar to that required in the job specifications. Once the panels had cured they were placed horizontally on styrofoam pads with more styrofoam around the edges (Photo 18).

32. Once the panels had been positioned on the pads, a protective coating material was applied to the exterior face of each.

Application of Coatings to Test Panels

33. All of the coatings were applied to the brick panels using a paint roller. The suppliers recommended rate of applications was followed. Cracks in the masonry mortar were filled with a clear silicone rubber caulking material before applying the coatings. All the panels were dry, and cleaned to remove any loose mortar, paints, or other contaminants which would prevent the coatings from penetrating and adhering to the

surface of the panels. Two coats of each material were rolled on the test panel, allowing each coat to dry for at least 2 hours before applying a second coat.

34. Below is the rate of application and mixing procedures that were used for each coating material tested.

a. Material A. The material was thinned as recommended by the supplier, by adding 1 part of the thinner, to 4 parts of the material by volume. The material and thinner were then mixed together using a wooden spatula. The material was applied at a ratio of 300 sq ft per gallon. Panel No. 3 was coated using the method above. For Panel No. 2 the first coat applied was thinned by adding 1 part of the thinner to 2 parts of the material. This was done to get better penetration of the first coat into the bricks. The second coat was applied using the recommended mixing proportions.

b. Material B. The material is a one component epoxy resin system, and was not mixed and thinned before application. The material was applied at a rate of 300 sq ft per gallon.

c. Material C. This material is a thin two component epoxy resin. The epoxy resin was mixed by adding 1 part component A and 1 part component B by volume, then stirring. The mixed material was allowed to stand for 1/2 hour, stirring every 10 minutes. The material was applied at a rate of 100 sq ft per gallon.

d. Material D. The material is a one component system composed of a silicone resin dissolved in a hydrocabon. The mixture was applied at a rate of 15 sq ft per gallon.

e. Material E. The material is a thin two component epoxy resin. The epoxy resin was mixed by adding 1 part of component A to 1 part component B by volume, then stirring.

The mixed material was then allowed to stand for 30 minutes before application. The material was applied at a rate of 200 sq ft per gallon.

35. After the coatings had cured a continuous "dike" of modeling clay was placed around the edge of the coated face in order to pond the water for the freezing and thawing tests.

Freezing and Thawing Tests of Panels

36. The F-T tests of the panels were begun by first placing 100 ml of water on the face of each panel and distributing it evenly with a brush. However, the water tended to pond in the depressed faces of deteriorated bricks though the panel was was completely covered. The pads containing the panels were then placed in the -15°F freezing chamber.

37. Each morning the pads were removed from the chamber and placed on pallets out-of-doors in direct sunlight. As the panels thawed out-of-doors the coatings were subjected to the ultraviolet rays of the sun to check for unacceptable amounts of coating discoloration. When it rained, the panels were placed inside the laboratory at approximately 73°F. At the end of each work day the pads were once again brushed with 100 ml of water and returned to the freezing chamber overnight. On holidays and weekends the panels remained in the freezing chamber. The panels received 50 cycles.

Cracked panel

38. During the curing process panel number 2 developed a vertical separation at the interface of the bricks and the mortar joint (Photo 20). Rather than refabricate the panel it was decided that this represented a condition existing in many of the structures and therefore afforded an opportunity to devise a corrective technique prior to the coating application. Once the panel was placed horizontally on the pad the separation was closed and a bead of silicone caulking was placed the complete length of the separation. A bead was also placed on the non-separated vertical joint. The coating was then applied after the silicone cured for 20 hours.

Panel test results

39. Observations were made on each panel at the end of each cycle to note any changes that might have occurred. The following are descriptions of each panel and any significant observations.

a. Panel 1. One nondeteriorated brick developed a small vertical crack close to a corner at the end of the 4th cycle. This crack neither propagated nor caused a pop off by the end of the 50th cycle. The crack appeared to be approximately 1/16-inch deep. A mortar joint separation developed at the end of the 14th cycle. The two vertical joints had completely separated at the end of 50 cycles (Photo 19).

b. Panel 2. A small crack in a mortar joint developed at the end of the 9th cycle. This crack developed into a sepration at the end of the 40th cycle. The vertical joints protected by the silicone caulking remained intact and unaffected at the end of 50 cycles (Photo 21).

c. Panel 3. A crack approximately 1/16-inch deep developed across the width of a brick at the end of the 40th cycle. A mortar joint separation developed at the end of the 47th cycle. Both vertical joints had separated by the end of 50 cycles (Photo 23).

d. Panel 4. Several small hairline cracks developed in several bricks at the end of the 5th cycle. The cracks were slightly more pronounced at the end of the 8th cycle. The test on this panel was discontinued at the end of the 40th cycle due to extensive separations of mortar joints (Photo 25). The bricks remained unchanged.

e. Panel 5. Several small hairline cracks developed in several bricks at the end of the 8th cycle. A crack developed in a mortar joint at the end of the 9th cycle. The test on this panel was discontinued at the end of the 40th cycle due to extensive separations of mortar joints (Photo 27). The bricks remained unchanged.

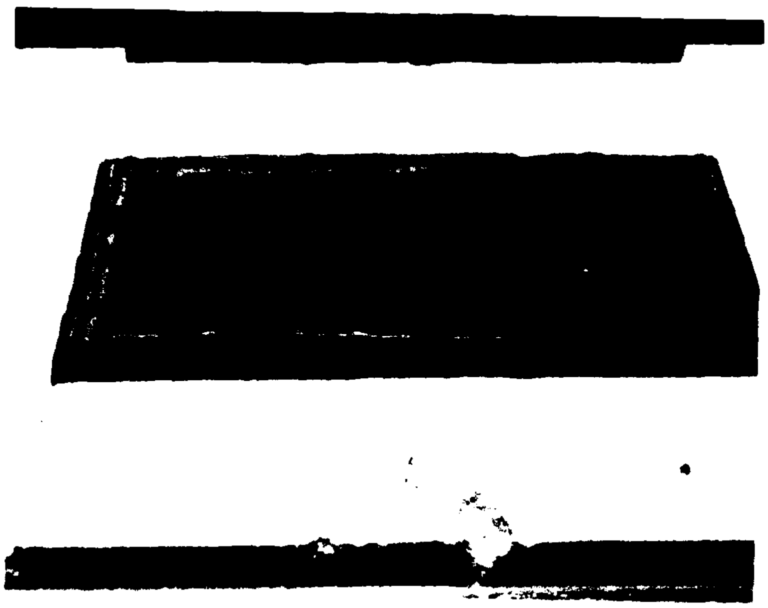


Photo 18. Panel 1 - 0 cycles F-T coating C

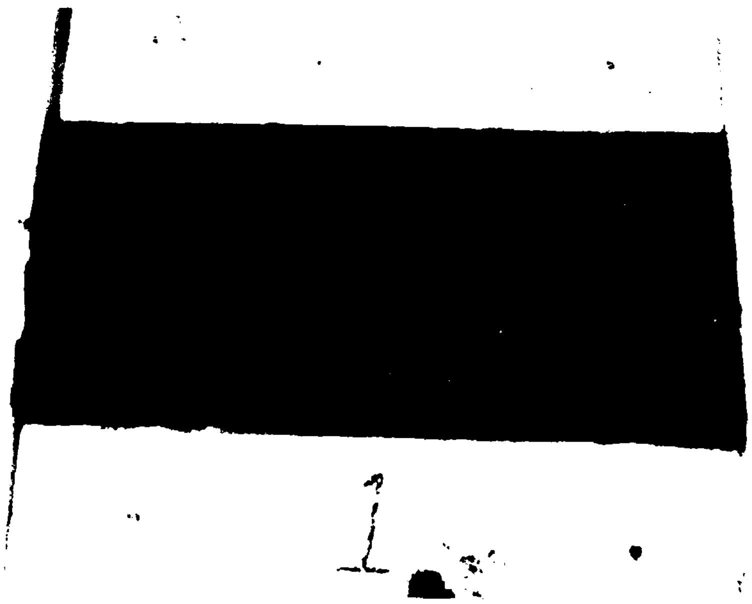


Photo 19. Panel 1 - 50 cycles F-T

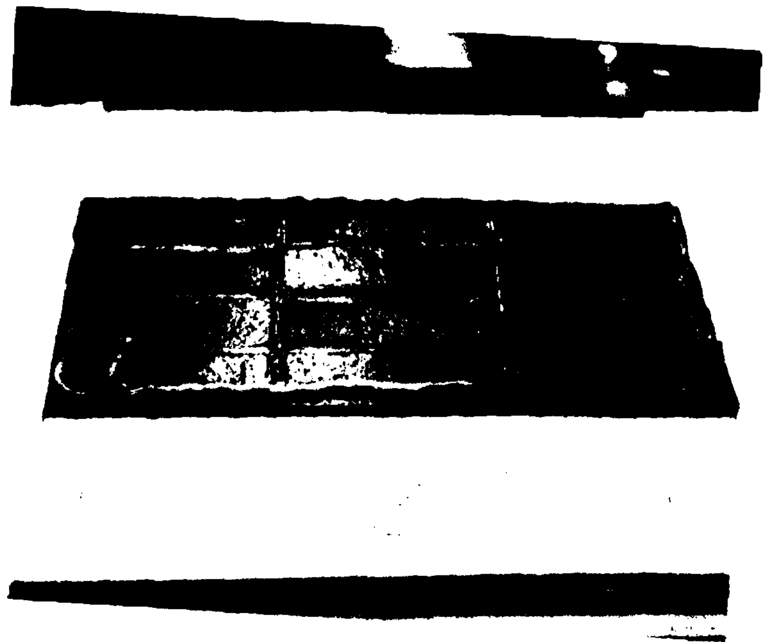


Photo 20. Panel 2 - 0 cycles F-T coating A with thinner

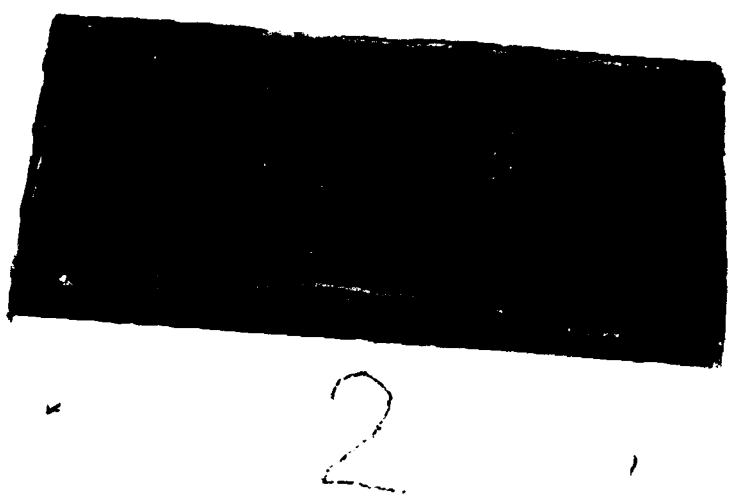


Photo 21. Panel 2 - 50 cycles F-T

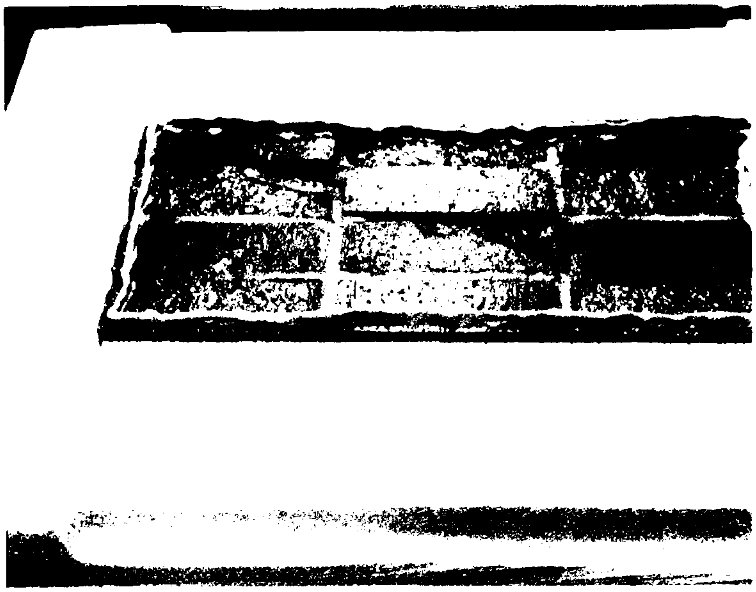


Photo 22. Panel 3 - 0 cycles F-T Coating A without thinner

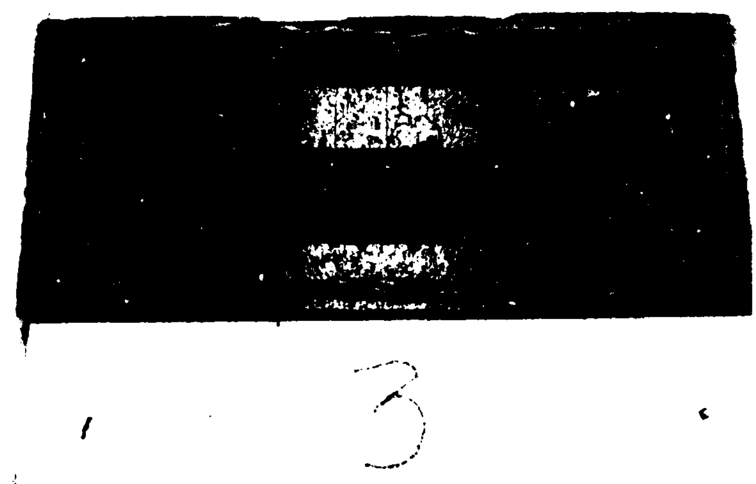


Photo 23. Panel 3 - 50 cycles F-T

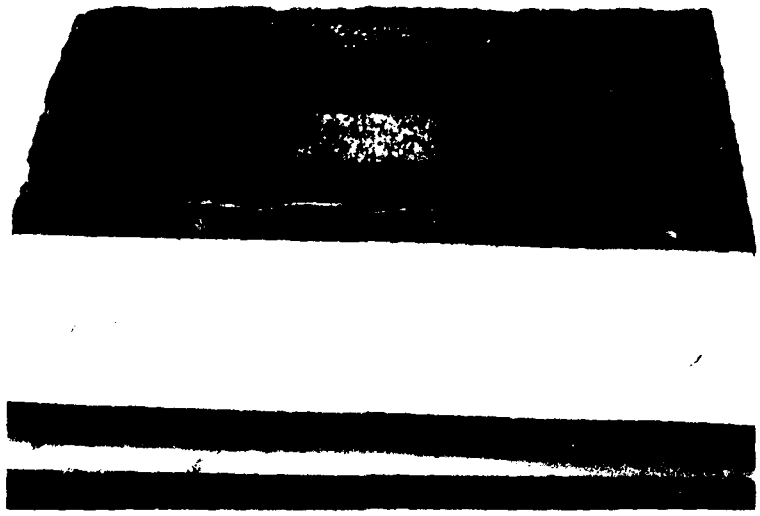


Photo 24. Panel 4 - 0 cycles F-T Coating E

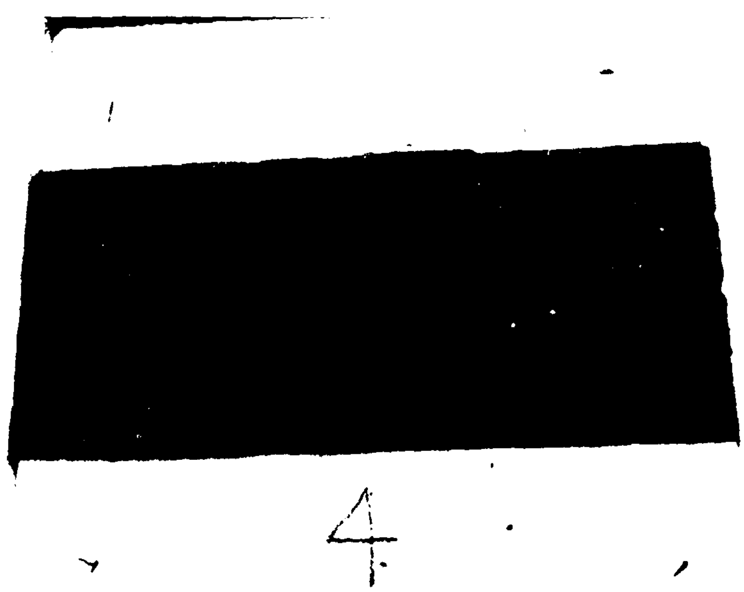


Photo 25. Panel 4 - 40 cycles F-T

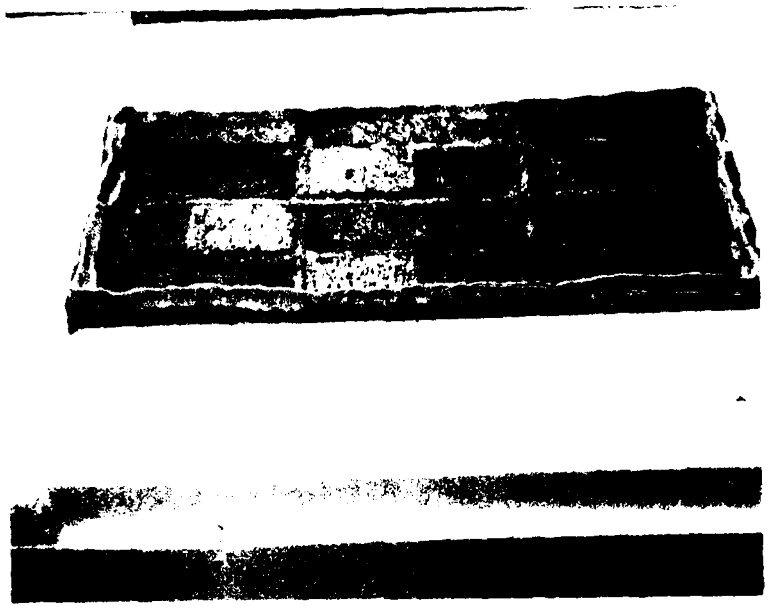


Photo 26. Panel 5 - 0 cycles F-T Coating B

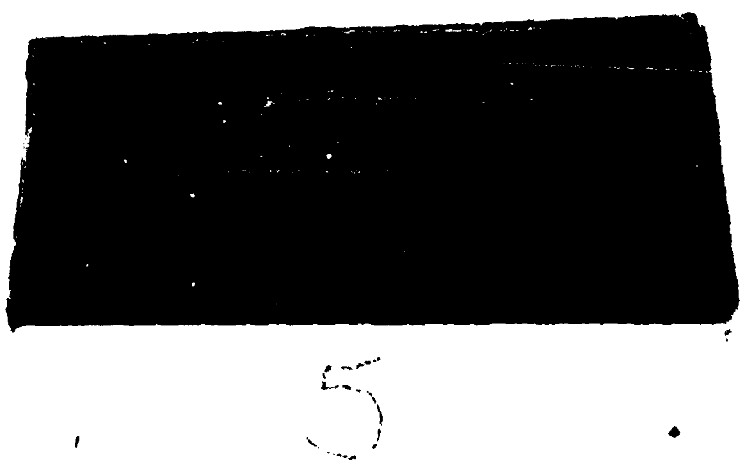


Photo 27. Panel 5 - 40 cycles F-T

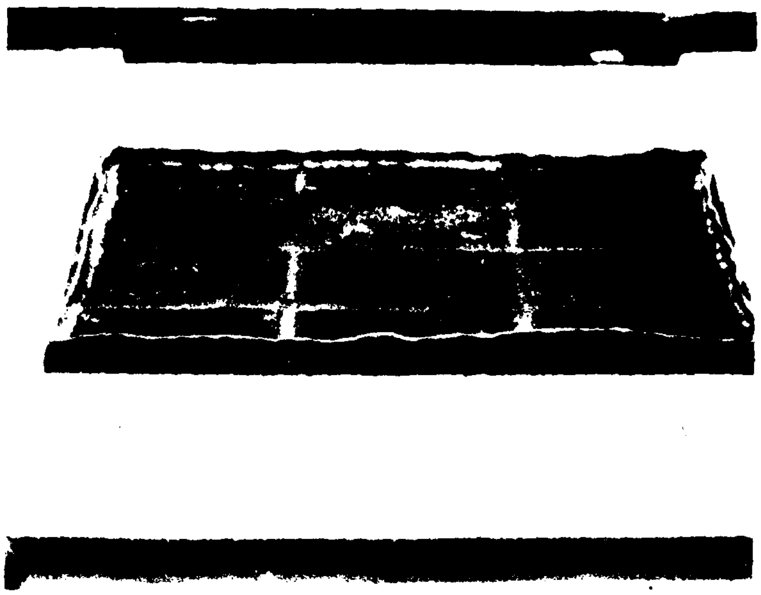


Photo 28. Panel 6 - 0 cycles F-T Coating D

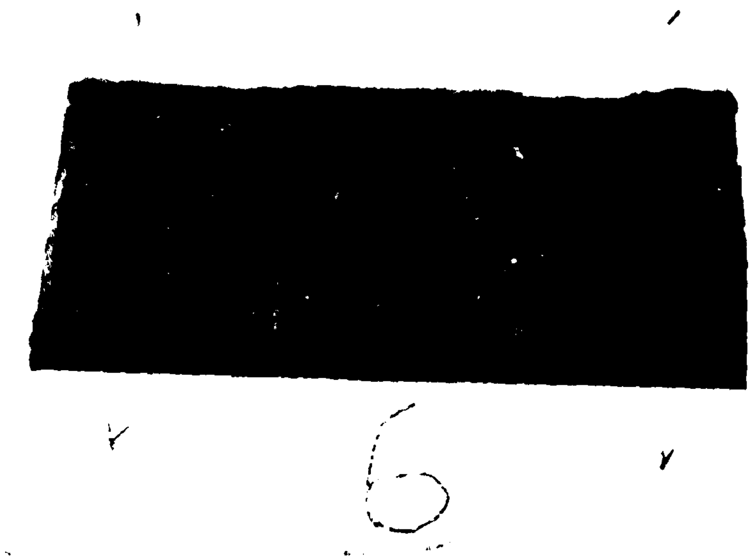


Photo 29. Panel 6 - 50 cycles F-T

f. Panel 6. A slight crack developed in a deteriorated brick at the end of the 3rd cycle. Observations at the end of the 5th, 9th, and 50th cycles showed that the crack had not propagated. One vertical joint had separated by the end of 50 cycles.

Discussion

40. All six coatings very effectively protected the bricks from frost damage (F-T); however, it is very apparent that some mechanism must be used to prevent water migration through separations in mortar joints. None of the coatings were able to bridge over these separations even though the coatings protected the mortar against deterioration. The most effective method to stop this migration is to caulk all joint separations with a silicone caulking compound. It is also suggested that a buildup of several layers of coating material over nonseparated joints probably will prevent future separations. No significant color change was observed in any of the panels.

PART V: FAILURE MECHANISM AND RECOMMENDATIONS

Failure Mechanism

41. The petrographic examination showed that the exterior surface of one brick had an absorption of 4.5 percent while the interior of the specimen had an absorption of 12.6 percent. The interior value compares closely with the absorption values of the complete brick, whether deteriorated or nondeteriorated.

42. The interior of the brick can absorb a greater volume of water at a faster rate than can the 1/4- to 1/2-in. face layer. When freezing takes place after absorption, the expansion and pressure of the interior is greater than in the face layer resulting in a separation at the interface of these two regions. As the separation gets wider the phenomenon becomes more pronounced until total separation takes place and the face falls off exposing the interior to further deterioration.

43. Once the interior is exposed the layering continues to take place at varying rates.

44. Test results indicate that the destructive mechanism is the critical saturation of two different absorption regions of the brick followed by expansion and stress gradients caused by the freezing of absorbed water. The deterioration continues at varying rates once initial separation of the face has occurred producing an unacceptable situation.

45. In several instances nondeteriorated bricks showed definite signs of deterioration having begun. This clearly indicates that the problem is more wide-spread than field observations indicate and that remedial action is necessary.

46. The second phase of this study was designed to find a protective coating that would keep the saturation of the bricks from reaching a critical level and thereby stop the deterioration.

Recommendations

47. Based on these tests the following is the recommended listing of the most effective to least effective of the coatings.

Order	Coatings[a] (Panel Number)
1	A (without thinner) (panel 3)
2	A (with thinner) (panel 2)
3	B (Panel 5)
4	E (Panel 4)
5	C (Panel 1)
6	D (Panel 6)

Note: (a) For complete descriptions see Chemical Coatings Section of this report.

Field Application

48. The test panels were all coated using a paint roller. A paint roller or spray equipment would be satisfactory for field application. The coatings are all thin and can be sprayed with ease. If spray equipment is to be used, it is recommended that airless spraying equipment be used, and that two coats of the material be applied waiting at least 2 hours between coats.

REFERENCES

1. American Society for Testing and Materials, "Standard Specifications for Facing Brick (Solid Masonry Units Made From Clay or Shale)," ASTM C 216-64, Philadelphia, Pa.
2. U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, with quarterly supplements, Vicksburg, Miss., August 1949.
3. Kornerup, A., and Wanscher, J. H., Metheun Handbook of Colour, 2d ed., Metheun and Co., Ltd., London, England, 1967.

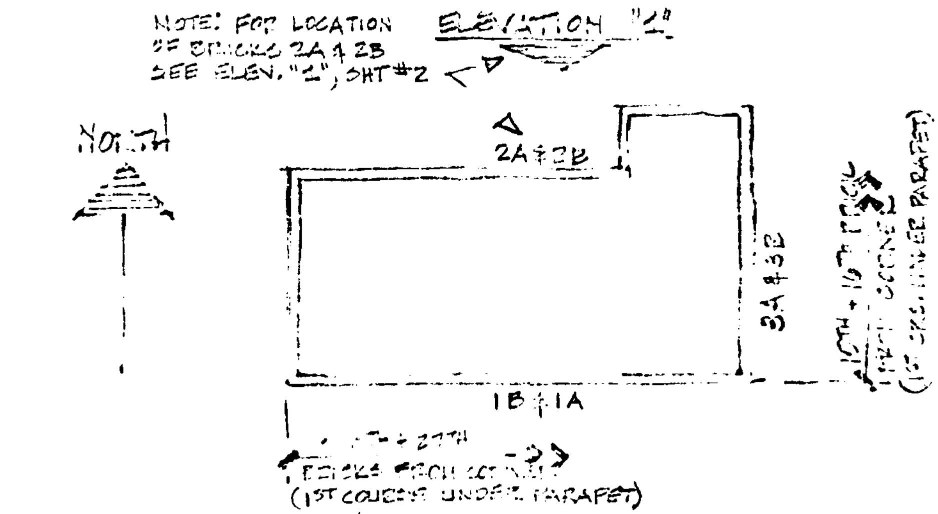
APPENDIX A

ARCHITECT'S SKETCHES

GENERAL NOTES:

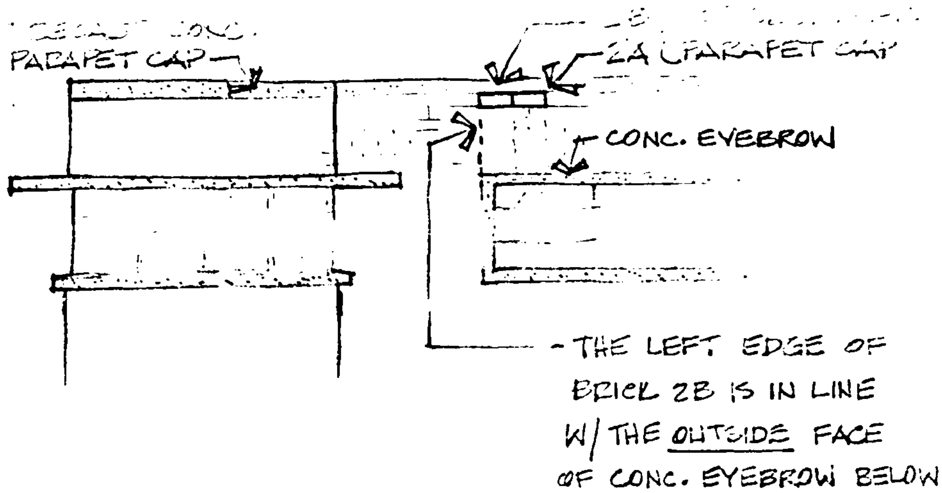
1. ALPHABETICAL SUFFIX ON ALL BRICK DENOTES CONDITION OF BRICK THUS: A = GOOD BRICK
B = DETERIORATED BRICK
2. NORTH ARROWS SHOWN ON PLAN VIEWS ARE FROM THE INSTRUCTIONS OF FIELD OFFICE PERSONNEL AND SHOULD BE FAIRLY ACCURATE.

W. L. MAYO ..... L & D 14
(BOYD WOOLRIDGE - REPAIRMAN)



PLAN VIEW OF LOCK CONTROL BLDG.

SHT #1
10 MAY 7?



ELEVATION "1"

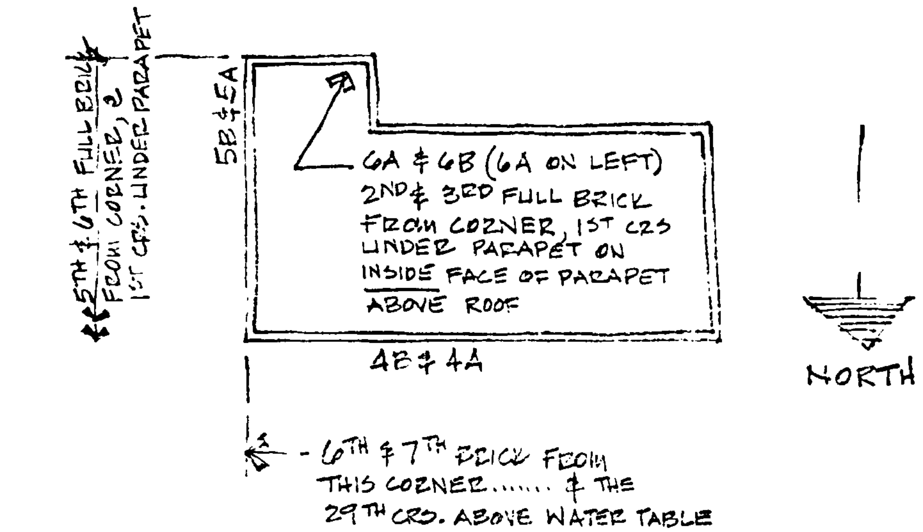
W. D. MAYO ..... L&D 14

REMAINING BLDGS @ L&D 14

1. NO VISIBLE DAMAGE AT UPSTREAM CONTROL SHELTER (LANDWALL)
2. " " " " " " " (RIVERWALL)
3. " " " " DOWNSTREAM " " (LANDWALL)
4. " " " " PAINT & OIL STORAGE BLDG.
5. " " " " VISITOR CENTER BLDG.

SHT #2
10 MAY 78

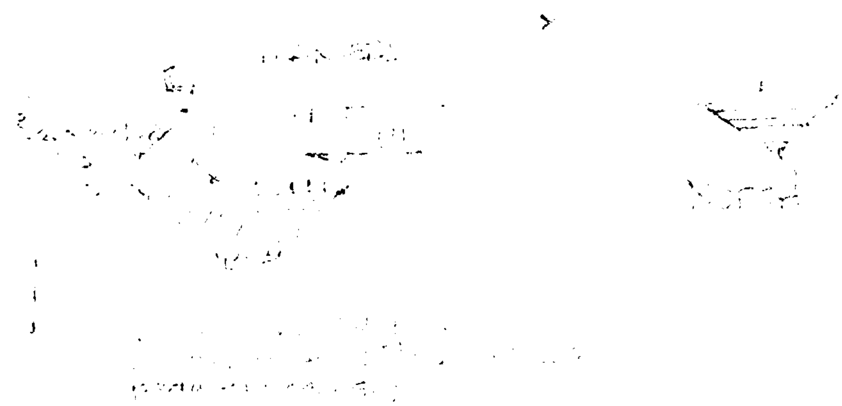
ROBERT S. KERR .... L & D 15
(KENNETH WOFFORD - LOCKMASTER)



PLAN VIEW OF LOCK CONTROL BLDG

(REMAINING BLDGS @ L+D 15 CONTINUED ON SHT #4 OF 11)

SHT #3
10 MAY 78



[illegible]

[illegible] WAS A [illegible] BAD [illegible] WERE [illegible] THE [illegible]

[illegible] BAD [illegible] WERE NOTED.

2. [illegible] CONTROL SHELTER [illegible]

EXCEPT ONLY 6 BAD BRICKS.

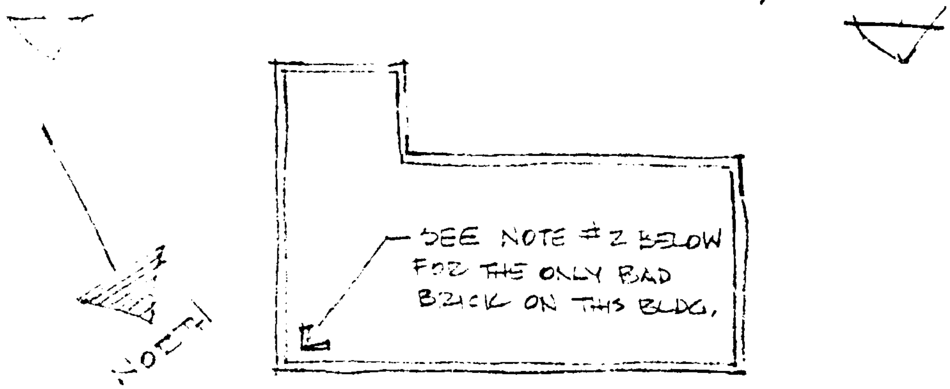
3. BAD [illegible] WAS NOTED ALONG [illegible] AREAS OF LANDSCAPE

PLANTERS [illegible] VISITOR PARKING.

[illegible] #4

10 MAY 78

WEBBERS FALLS .... L&D 16.
(KEN HUST - LOCKMASTER)

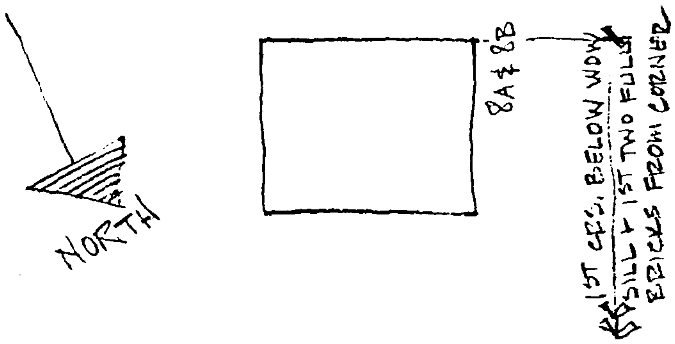


PLAN VIEW OF LOCK CONTROL BLDG.

1. OUTSIDE FACE OF BLDG. APPEARED TO BE SOUND.
2. ABOUT 6 OR 7 BAD BRICK WERE NOTED ON THE INSIDE FACE OF PARAPET AS INDICATED ABOVE.
3. PAINT & OIL BLDG IS O.K.
4. UPSTREAM CONTROL SHELTER (RIVERWALL) IS O.K.

SHT #5
10 MAY 78

WEBBERS FALLS ...... L&D 16 (CONTINUED)



PLAN VIEW OF D.S. CONTROL SHELTER

1. VISITOR CENTER SHOWS NO BAD BRICK

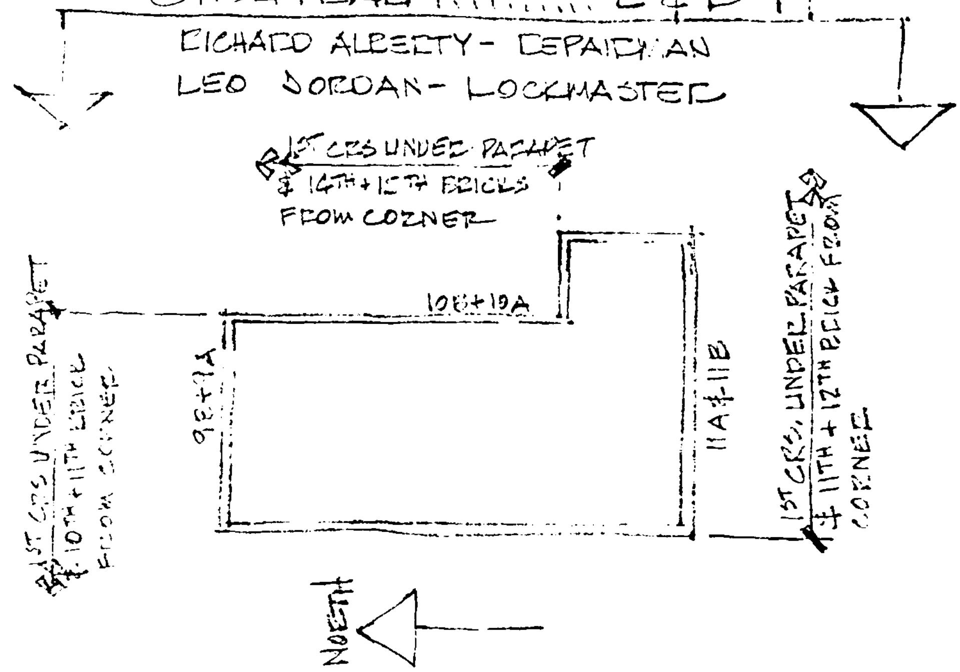
ON 10 MAY 1978, MR BOB DENSON, VICKSBURG, CURT WEDDLE, ROBT. S. KERR RES. ENGR., & JOHN NIXON, DISTRICT ARCHITECT, DISCUSSED INITIAL FINDINGS FOR ABOUT ONE HOUR. AT THE REQUEST OF MR DENSON, MR WEDDLE AGREED TO OBTAIN COPIES OF CONTRACT SPECIFICATIONS FOR THE BRICK USED AT L&D 14 THROUGH L+D 16. THESE COPIES WILL BE MAILED TO MR. DENSON AS SOON AS THEY ARE IN THE HANDS OF NIXON.

SHT #6
10 MAY 78

CHOUTEAU .... L&D 17

RICHARD ALBERTY - REPAIRMAN

LEO JORDAN - LOCKMASTER



PLAN VIEW OF LOCK CONTROL BLDG

REMAINING BLDGS @ L&D 17.

1. PAINT & OIL STORAGE BLDG APPEARS OK

2. CONTROL SHELTER (UPSTREAM) APPEARS OK BUT MANY BRICK ARE DISCOLORED, THIS PROBABLY INDICATES THE PRESENCE OF MOISTURE. THERE IS NO PATTERN TO THE DISCOLORED BRICK. ONE BAD BRICK WAS NOTED AT THE NW CORNER OF BLDG.

3. CONTROL SHELTER (DOWNSTREAM) SHOWS NO BAD BRICK BUT SAME DISCOLORING AS NOTE #2.

(CONTINUED ON SHT # 8

SHT # 7

11 MAY 78

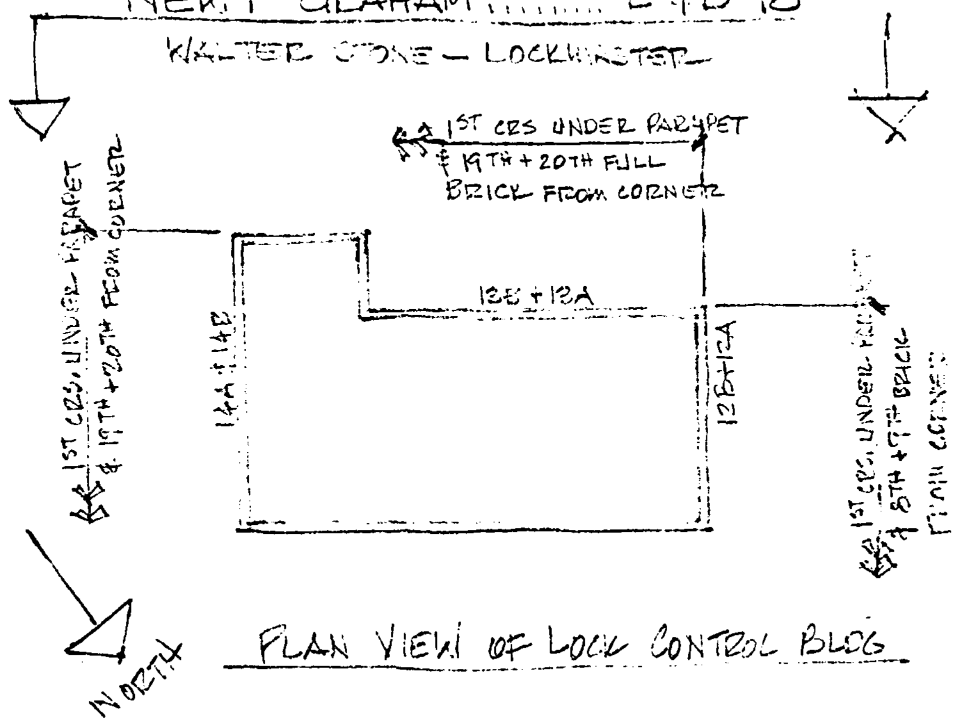
CHOUTEAU ...... L&D 17 (CONTINUED)

4. PLANTERS WERE NOTED AS HAVING BAD BRICK AT RANDOM LOCATIONS.

5. NO BAD BRICK WERE DETECTED AT THE VISITOR CENTER, THERE IS SOME MINOR DISCOLORATION ON BRICK AT ALL FOUR ELEVATIONS.

NEWT GRAHAM .... L&D 18

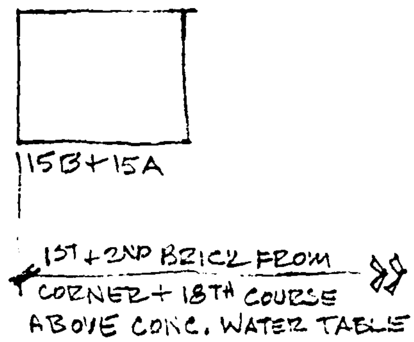
WALTER STONE — LOCKMASTER



FLAN VIEW OF LOCK CONTROL BLDG

SHT # 8
11 MAY 78

NEWT GRAHAM.......... L+D 18 (CONTINUED)



PLAN VIEW OF D.S. CONTROL SHELTER (LANDWALL)

REMAINING BLDGS @ L+D 18

1. NO VISIBLE DAMAGE AT VISITORS CENTER
2. " " " " PAINT + OIL STORAGE BLDG
3. HEAVY DAMAGE WAS NOTED AT PLANTERS
4. UPSTREAM CONTROL SHELTER (LANDWALL) HAS FOUR BAD BRICK.

SHT #9
11 MAY 78

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Denson, Robert H.
Investigation of deterioration of brick in navigation lock control house structures, Tulsa District : Final report / by Robert H. Denson, G. Sam Wong, Tony Husbands (Structures Laboratory, U.S. Army Engineer Waterways Experiment Station) ; prepared for U.S. Army Engineer District, Tulsa. -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station, 1980.
41, 9 p. : ill. ; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; SL-80-14)
Cover title.
Bibliography: p. 41.

1. Bricks. 2. Hydraulic models. 3. Hydraulic structures. 4. Locks (Hydraulic engineering). 5. Protective coatings. I. Wong, G. Sam. II. Husbands, Tony. III. United States. Army. Corps of Engineers, Tulsa District. IV. United States. Army Engineer Waterways Experiment Station. Structures Laboratory.

Denson, Robert H.
Investigation of deterioration of brick : ... 1980.
(Card 2)

V. Title VI. Series: Miscellaneous paper (United States. Army Engineer Waterways Experiment Station) ; SL-80-14.
TA7.W34m no.SL-80-14

END

DATE

FILMED

7-81

DTIC